national accelerator laboratory

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Water Resources and Requirements of the National Accelerator Laboratory

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In this note we examine the water resources and requirements of the NAL. We do not include the several low conductivity water systems, since they, on the whole, do not consume any water, but simply use water as a heat exchange medium. Nor do we include any water required for irrigation. It is hoped that blowdown water from the Main Ring and Booster ponds can be used to meet all irrigation requirements.

1. Resources

1.1 Rain Water

We prefer rain water for industrial use over all other sources because of the lower mineral content. Samples of surface runoff have an average total dissolved solids content of about 225 ppm. All other sources (wells, Fox River, Kress Creek) average about 450 ppm. We presently collect runoff in the Main Ring basin, Casey's Pond Basin, Lake Law basin, Ephemeral Lake basin, Sea of Evanescence basin, Indian Creek basin north of our pumping station, and Kress Creek west of our pumping station. These areas total about 5000 acres not counting the area of our reservoirs, which will be dealt with separately later. The average rainfall for this area is 33.8" per year. Using a runoff coefficient of .2, we would expect to collect 920,000,000 gallons which is an average of 1750 gpm. Referring to Table I, we see that this runoff is quite unevenly distributed in time, with a maximum flow in April and May, falling off to very low rates from July through February.

TABLE I
Rain Data

Month	Average Rainfall	Ave.Monthly Runoff Coeff.	Average Runoff
Jan.	1.96"	.18	.35"
Feb.	1.54	.18	.28
Mar.	2.50	.36	.90
April	2.89	.46	1.33
May	3.74	.37	1.38
June	4.28	.12	.51
July	3.15	.10	.32
Aug.	3.47	.08	.28
Sept.	3.26	.07	.23
Oct.	2.87	.14	.40
Nov.	2.23	.10	.22
Dec.	1.91	.20	.38
Total	33.8 "		6.58"

Runoff basins may be seen in Figure 1.

1.2 Fox River

The recently completed Fox River pipe line has a rated capacity of 1200 gpm. The Laboratory is permitted to pump water from the Fox River whenever the flow rate of the river exceeds 200 cubic feet per second. This flow rate is exceeded, on the average, during ten months per year. Thus, the maximum pumping rate would, on the average, be $\frac{10}{12}$ x 1200 or 1000 gpm.

1.3 Kress Creek

Kress Creek is a small stream that crosses the northern portion of the NAL site. Its flow is highly variable, ranging from several thousand gpm down to a few hundred gpm. Its flow is augmented by runoff from a considerable portion of the northern part of the site. There is some evidence of industrial and residential use of this stream, with the result that the water quality is somewhat variable. Our understanding with the AEC is that we may divert a maximum of 25% of the flow at the eastern boundary of the site. Quite by accident, we discovered last year that an abandoned 8" pipeline ran under Kress Creek and the Lake Law reservoir. We breached the pipeline at both places and pumped a considerable quantity of water through it last year. Taking into account the variability of the flow rate and the restriction on the portion we may pump, one could guess that a flow rate of 200 gpm, averaged over the year, could be achieved, in addition to the runoff collected from the basin that drains into Kress Creek.

1.4 Shallow Wells

Four shallow wells have been drilled into the Silurian Dolomite aquifer. One has been capped and three are presently in use. These are:

Well	Location	Maximum Flow
#1	Central Utility Plant	500 gpm
#3	West of Master Substation	250
	Village	100

These wells are being used for the domestic water system both in the village and at the main site. Though the present rate of use is less than 200 gpm, there is some question whether these wells could sustain much greater flow rate for a long period of time. Therefore, we will guess that an additional 200 gpm is available for cooling on a long term basis. This estimate may be modified in either direction as we gain experience with this system.

1.5 Deep Well

A deep well has been drilled into the Cambrian-Ordovician sandstone aquifer. This well has a rated capacity of 1000 gpm. Since this aquifer is a prime source of water for surrounding communities, and since the aquifer is not being recharged at an appreciable rate, we would consider its use only in dire emergencies.

1.6 Minor Sources

The sewage treatment plant now being built west of the accelerator will have an effluent discharge rate of about 30 gpm. This will be fairly high quality water, comparable to our other sources in mineral content. Allowing for some evaporation, we estimate that 20 gpm will reach our Indian Creek pumping station. The sewage system in the Village discharges about 15 gpm of which we expect to recover about 10 gpm. A portion of the blowdown from the cooling ponds will be recovered after being purified. This will be directly by running into field tiles that empty into the Main Ring Reservoir, or indirectly by decreasing the amount of rainfall that seeps into the ground in the area of the blowdown fields and thereby increasing the runoff coefficient. We will guess that the net effect corresponds to a flow of about 30 gpm.

A source of water which is quite significant but impossible to estimate is the flow out of the field tiles. This is subsurface water draining out of the tile systems which were installed in a number of locations on the site by the previous owners. We will ignore this source, but at the same time we will ignore a flow of opposite sign, namely the exfiltration out of our several reservoirs. This latter flow is also impossible to estimate. If these two flows are of similar magnitude, they will tend to cancel.

We may now summarize our water resources during a time of average rainfall as follows:

Rainfall Runoff	:	1750 "
Fox River Pipeline	:	1000 "
Kress Creek	:	200 "
Shallow Wells	:	200 "
Deep Well	:	1000 "
Minor Sources	:	60 "
		4210 "

If we do not consider the deep well, we still have approximately 3200 gpm available.

Let us examine the situation during a time of a 20 year minimum rainfall. The annual rainfall during a 20 year minimum is 25 inches. Using the same 5000 acre collection area, but guessing that the collection coefficient has decreased to .1, we calculate the runoff to be 650 gpm. Let us assume that the Fox River is below the flow rate required for pumping for four months during this year. We then have available an average of 800 gpm from this source. We will assume that Kress Creek has half of its normal flow, yielding 100 gpm. The shallow wells and minor sources would be unaffected.

In summary, during a time of 20 year minimum rainfall, we would expect to have available:

Rainfall Runoff	:	650 gpm
Fox River Pipeline	:	800 "
Kress Creek	:	100 "
Shallow Wells	:	200 "
Deep Well	:	1000 "
Minor Sources	:	60 "
		2810 gpm

Neglecting the deep well, we would still hae about 1800 gpm available.

2. Water Requirements

2.1 Main Accelerator

Let us make the following assumptions:

a) The main accelerator is operated at a duty factor of 90%.
b) 90% of the heat generated is transferred to the pond water. 10% is transferred to the air by convection and radiation from the magnets and pipes, and into the ground from the cables.
c) The motors powering the LCW and pond pumps operate at 90% efficiency. The heat generated by motor losses is dissipated in the air.

The following loads were observed for the main ring at the master substation in July, 1972.

200 GeV -13 MW
300 GeV - 32 MW

We project a load of 87 MW for 400 GeV. Taking into account duty factors and water pump power consumption we obtain for non-air cooler augmented times:

200GeV: (13+1.5) .9 x .9 = <u>11.7 MW</u>
300GeV: (32+1.5) .9 x .9 = <u>27.1 MW</u>
400GeV: (87+1.5) .9 x .9 = <u>71.5 MW</u>

The installation of one air cooler per service building scheduled for summer 1973 alters the main accelerator water load during 4 or 5 hot months. Let us assume it is a 20-year hot year (and correspondingly dry) enabling the air coolers to be turned on May 1st and off on October 1st. The average air temperature for the 5 month period is 70+ 77+77+77+74/5=75°F. The coolers dissipate 22.8 MW per°F temperature difference between ambient air and return LCW. This effect at various accelerator energy levels is as below:

<u>200 GeV</u> 102°F Return -75° = 27°F ΔT
27° x 22.8 x 24 Buildings = 14.8 MW

Since this is over the actual load, it doesn't represent reality. The air temperature will go over 75° and thus there will be some pond evaporation. Thus an estimate of 10 MW is more in line.

<u>300 GeV</u> 114°F Return -75 = 39°F ΔT
39 x 22.8 x 24 = 21.4 MW

Since this is only part of the 32 MW load the average temperature assumption is valid.

$$\underline{400\text{ GeV}}\quad 161^{\circ}\text{F Return } -75^{\circ} = 86^{\circ}\text{F } \Delta T$$
$$86 \times 22.8 \times 24 = 47 \text{ MW}$$

Again since this is only part of the load the average temperature assumption is valid. Thus for 5 hot months the power consumption would be as follows:

200 GeV (13 + 1.5 -10) x.9 x.9 = 3.6
300 GeV (32 + 1.5 -21) x.9 x.9 = 10.12
400 GeV (87 + 1.5 -47) x.9 x.9 = 33.6

2.2 Booster

We assume that the booster operates at 95% duty factor, and that 90% of the power consumption recorded at the master substation ends up as heat in the cooling water. Having observed a 2.6 MW load on July 20, 1972, we calculate: 2.6 x .9 x .95=2.2 MW average heat dissipated by the cooling water.

2.3 Linac

On July 20, 1972, 1.6 MW was observed to the Linac. Again assuming 95% duty factor and 90% of the heat removed by the cooling water, we calculate 1.6 x .95 x .9 = 1.4 MW average heat removed by the cooling water.

2.4 Main Ring R F

According to Quentin Kerns, approximately 70% of the heat generated is transferred to the cooling ponds, 30% to the chilled water system of the Central Utility plant. There are two feeders from the master substation. Feeder #20 supplied .64 MW, feeder #45 supplied 3.4 MW when measured recently. Since feeder #45 also powers Main Ring LCW pumps that load must be subtracted:
3.4 - 1.6 = 1.8 MW.
Total power consumption is then .64 + 1.8 = 2.4 MW. Assuming a 90% duty factor, the average power is .9 x 2.4 = 2.2 MW. Of this, 70% will be dissipated by the main ring cooling ponds and 30% by the C.U.P. cooling system. .7 x 2.2 = 1.5 MW, .3 x 2.2 = .7 MW.

2.5 Central Utility Plant (C.U.P.)

On July 21, 1972, the power consumption of the C.U.P. was 2.5 MW. This was a 95°F day, with high humidity. If we assume that one kilowatt is required to produce one ton of cooling (3.516KW), then this 2.5 MW is producing 2.5 x 3.516 = 8.79 MW of cooling. Some of this is heat load from the Linac and Main Ring R F: 8.79 - .7 -1.4 = 6.7 MW. This must be air conditioning load not related to machine operation. The high rise laboratory building is to have a peak load of 2800 tons of air conditioning or 9.8 MW. Adding the two loads yields 7.6 + 9.8 = 17.4 MW. Let us assume that the average air conditioning load is 1/3 the peak load. Thus, adding back in the peak load's electric driving load and dividing by three yields the average air conditioning heat load:

$$\left(17.4 + \frac{17.4}{3.516}\right) \div 3 = 7.4 \text{ MW}$$

Add to this the RF and Linac loads plus their driving loads to obtain average total heat load for the C.U.P.:

7.4 + (.7 + 1.4) 4.516/3.516 = 10.1 MW

2.6 Proton Lab

A cooling pond now being designed for the proton lab is intended to dissipate 2 MW. Using a duty factor of .8, we obtain an average heat load of 2 x .8 = 1.6 MW

Service Building P-1 receives its cooling from water pumped from the main ring reservoir through the abandoned pipe line. The water goes once through the exchanger and then is dumped into the main ring ditch, thence back to the reservoir. With a load of 2 MW and using a duty factor of .8 the average heat load is then 2 x .8 = 1.6 MW

Summary

The following table summarizes all loads which evaporate water:

7 Month Winter Operation

	Main Ring	Booster	Main Ring RF	C.U.P.	Proton Lab	Total
200 GeV	11.7	2.2	1.5	10.1	1.6	27.1 MW
300 GeV	27.1	2.2	1.5	10.1	1.6	42.5 MW
400 GeV	71.5	2.2	1.5	10.1	1.6	86.9 MW

5 Month Summer Operation

	Main Ring	Booster	Main Ring RF	C.U.P.	Proton Lab	Total
200 GeV	3.6	2.2	1.5	10.1	1.6	19.0 MW
300 GeV	10.1	2.2	1.5	10.1	1.6	25.5 MW
400 GeV	33.6	2.2	1.5	10.1	1.6	49.0 MW

Note that we make no attempt to predict a variation in either Main Ring RF or in Proton Lab heat loads with changing accelerator energy.

These total water cooled power consumptions can be translated into water consumptions as follows:

For Winter Operation

200 GeV: 27.1 MW = 177 gpm
300 GeV: 42.5 MW = 295 gpm
400 GeV: 86.9 MW = 567 gpm

5 Month Summer Operation

200 GeV: 19.0 MW = 124 gpm
300 GeV: 25.5 MW = 166.5 gpm
400 GeV: 49.0 MW = 320 gpm

3. Additional Water Losses

3.1 Normal Evaporation

During an average year, ponds in the Chicago area not used for cooling will evaporate about 34" of water. This is almost the same as the normal 33.8" of rainfall. Therefore, no allowance need be made for evaporation. Moreover, since the rainfall has essentially zero mineral content, the mineral content of the reservoirs will not increase.

The 20 year maximum net evaporation for a lake for this region is 14", net evaporation being total evaporation minus rainfall. This maximum comes at a time of minimum rainfall combined with low humidity and a high percentage of sunny days. When this occurs, we will attempt to reduce our evaporation losses by concentrating our stored water in the deeper reservoirs, thereby reducing the area exposed to evaporation. Let us assume that during this year of maximum evaporation 65% of our total of 192 acres of reservoirs is, on the average, exposed to evaporation. This 14" over 65% of our reservoirs corresponds to a loss rate of 89 gpm.

3.2 Blowdown

Blowdown is a term applied to the removal of a portion of the water in an industrial water system whose mineral content is too high, and replacement by fresh water of lower mineral content. It is considered good practice to limit the mineral content of water used in heat exchangers to 1800 ppm in order to limit the rate of fouling of heat exchanger tubes. Since our water sources have an average mineral content of 450 ppm, we require a blowdown rate of $\frac{450}{1800} = 1/4$ of our makeup rate. Thus, in a year of average rainfall, our winter water consumption is:

200 GeV: 5/4 x 177 = 212 gpm
300 GeV: 5/4 x 295 = 354 gpm
400 GeV: 5/4 x 567 = 680 gpm

In a year of 20 year minimum rainfall, we must add the net evaporation from our reservoirs before calculating blowdown:

Winter Operation

200 GeV: 5/4 (177 + 89) = 319 gpm
300 GeV: 5/4 (295 + 89) = 461 gpm
400 GeV: 5/4 (567 + 89) = 787 gpm

Summer Operation

200 GeV: 5/4 (124 + 89) = 266 gpm
300 GeV: 5/4 (166.5 + 89) = 319 gpm
400 GeV: 5/4 (309 + 89) = 497 gpm

The situation during a minimum rainfall year may in fact be somewhat worse than this, since the mineral content of the Fox River tends to rise in times of drought. This would require a blowdown fraction higher than 1/4, thereby requiring more makeup water. We shall not attempt to explore this quantitatively.

Blowdown is disposed of by injecting the water into perforated pipes buried 3 feet deep inside the Main Ring. The first line, installed last summer, is 600 feet long. It is now devoted to blowdown from the C.U.P. and Booster Pond. We made tests last year to determine how rapidly topsoil precipitates and filters out the mineral content of the blowdown water. We found, by measuring the mineral content of water in a series of test holes surrounding the perforated pipe, that about 50 feet of topsoil was required to reduce the mineral content from the initial 1000 ppm to the 450 ppm which is normal for ground water. We anticipate that the length of filtration through the topsoil will increase as the ground near the pipe becomes saturated with minerals. Two additional blowdown perforated pipes are now being installed. These are being connected to the discharge pipe of the pond pumps at A-3 and A-4. It is hoped the residual pressure of the discharge pipe will be sufficient to feed the perforated pipe, eliminating the need for separate pumps. It may be that several more blowdown lines for the Main Ring will be required in addition to these two.

4. Reservoirs and Pipelines

4.1 Reservoirs Required

In order to determine our water storage requirements, we might consider a period when the Fox River is below the flow rate above which we are permitted to withdraw water. The last time that this low water period exceeded four months was in 1934, when there was a six month low water period. Let us examine a four month low water period during the months June, July, August and September. Let us further assume that during this period of drought the rainwater runoff is negligible and that Kress Creek has run dry. This leaves us with 200 gpm from the shallow wells plus

60 gpm from minor sources. Our consumption over this four month period consists of the load evaporation of 320 gpm plus the 14" reservoir evaporation (now averaged over 4 months) of 274 gpm. Adding and multiplying by the blowdown factor yields:

$$(320 + 274)5/4 = 742 \text{ gpm}$$

The deficit of 742 - 260 = 482 gpm would have to come from our reservoirs. This flow rate for four months corresponds to 255 acre feet. Our present storage capacity is as follows:

Casey's Pond	100 acre feet
Main Ring Reservoir	40
Lake Law	140
Sea of Evanescence	100
Ephemeral Lake	100
Total	480 acre feet

This then appears to be more than adequate to meet the situation hypothesized above.

Another way to look at the question is to say that the reservoir system should be adequate to supply a flow equal to the flow from the Fox River pipeline during the occasional four month period when that source may not be available. If we take the average flow to be 1000 gpm, this, over a four month period, equals 539 acre feet. The plan to raise Lake Law would add about 15 acre feet. The plan to raise Ephemeral Lake and the Sea of Evanescence by means of a dam at the east end of Ferry Creek would add 80 acre feet, giving a new total of 480 + 80 + 15 = 575 acre feet, again adequate for our needs

A third way to consider our reservoir requirements is to say that it would be highly desirable to use rainwater runoff to the exclusion of all other sources because of its lower mineral content. To this end, we should be able to store the runoff which exceeds the average runoff during the year, so that runoff is available at a uniform rate. Referring to Figure 3, we see that during only three months, March, April and May, does the runoff exceed the average. The total runoff in excess of average for these three months is 1.96". Collected from 5000 acres, this amounts to 816 acre feet. Thus, our 575 acre feet of storage is not quite adequate from this point of view.

4.2 Pipelines

The distribution system for the cooling water is not complete. Referring to the reservoir and distribution system in Figure 2, it will be seen the Fox River pipeline empties into an open ditch which flows into the Main Reservoir. Pumps at that point feed a 14" pipeline which runs south to the footprint area, supplying water to the accelerator. A pump in the Main Ring reservoir near C-4 feeds an abandoned 20" pipeline which discharges into a ditch near N-1. This water then runs north to the main reservoir. The Indian Creek has two small sandbag dams. A design for a permanent pumping station from the dam at the point on Indian Creek near the Main Ring is in the active planning stage. This pump will feed a short pipeline crossing the Main Ring berm to discharge into the ditch inside the cooling ponds.

A pipeline from Lake Law to the Main Ring reservoir is highly desirable. This pipeline should have a branch coming from Ephemeral Lake.

The abandoned pipeline connecting Kress Creek and Lake Law should have a permanent pumping station.

Pumping in these areas with permanent pumps and pipelines is now being accomplished by means of portable pumps and hoses. This works moderately well during the summer, but would be extremely difficult during the winter.

Fire protection requirements are quite modest in terms of storage needed, but tax our system's pumping capacity. The maximum fire protection flow rate anywhere on site is 5700 gpm at the bubble chamber complex. For a four hour duration, this corresponds to 4 acre feet. However, the 5700 gpm rate exceeds the 4500 gpm capacity of the pumps at Casey's Pond. To supply the additional water, we plan to connect the deep well to the 14" pipeline. A pressure switch will start the deep well pump in response to a serious drop in pressure. This same system is also needed to feed water to the highrise laboratory building in case of a major fire emergency. It should be noted that the deep well is required only for very serious fire emergencies, since fires within the capabilities of the pumps at Casey's Pond would not activate the pressure switch.

5. Chemical Treatment

Our Policy with regard to chemical treatment of our water system has been to use the least possible amount, partly to prevent our site from becoming contaminated by noxious chemicals, and partly to protect wildlife and fish. We employ a biochemist as a consultant to advise us on the proper use of chemicals.

The Main Ring cooling ponds have so far not been much of a problem. We have used a little copper sulfate to inhibit algae growth. We are now adding spray nozzles to the discharge pipes of all the Main Ring pond pumps in order to increase the aeration of the pond water. This is thought to inhibit algae growth. An added benefit will be increased cooling capability.

The Booster Pond suffered from an algae bloom last year. This was brought under control by treatment with Cutrine, a proprietary chelated copper algaecide.

The Village oxidation pond had a duckweed bloom last year. This was brought under control by use of Diquat which is 6, 7 - dihydrodipyvido pyrazidinium dibromide.

BIBLIOGRAPHY

1. DUSAF, Compilation of Water Resources Data for NAL Report #C-4 April 7, 1970

2. Moses, Harry & Bogner, Mary A., Fifteen Year Climatological Summary Jan. 1, 1950 - Dec. 31, 1964, ANL-7084, Argonne National Laboratory, Argonne, Illinois, Sept. 1967

3. Roberts, Wyndham J. & Stall, John B., Lake Evaporation in Illinois Report of Investigation 57, Illinois State Water Survey, Urbana, Illinois, 1967

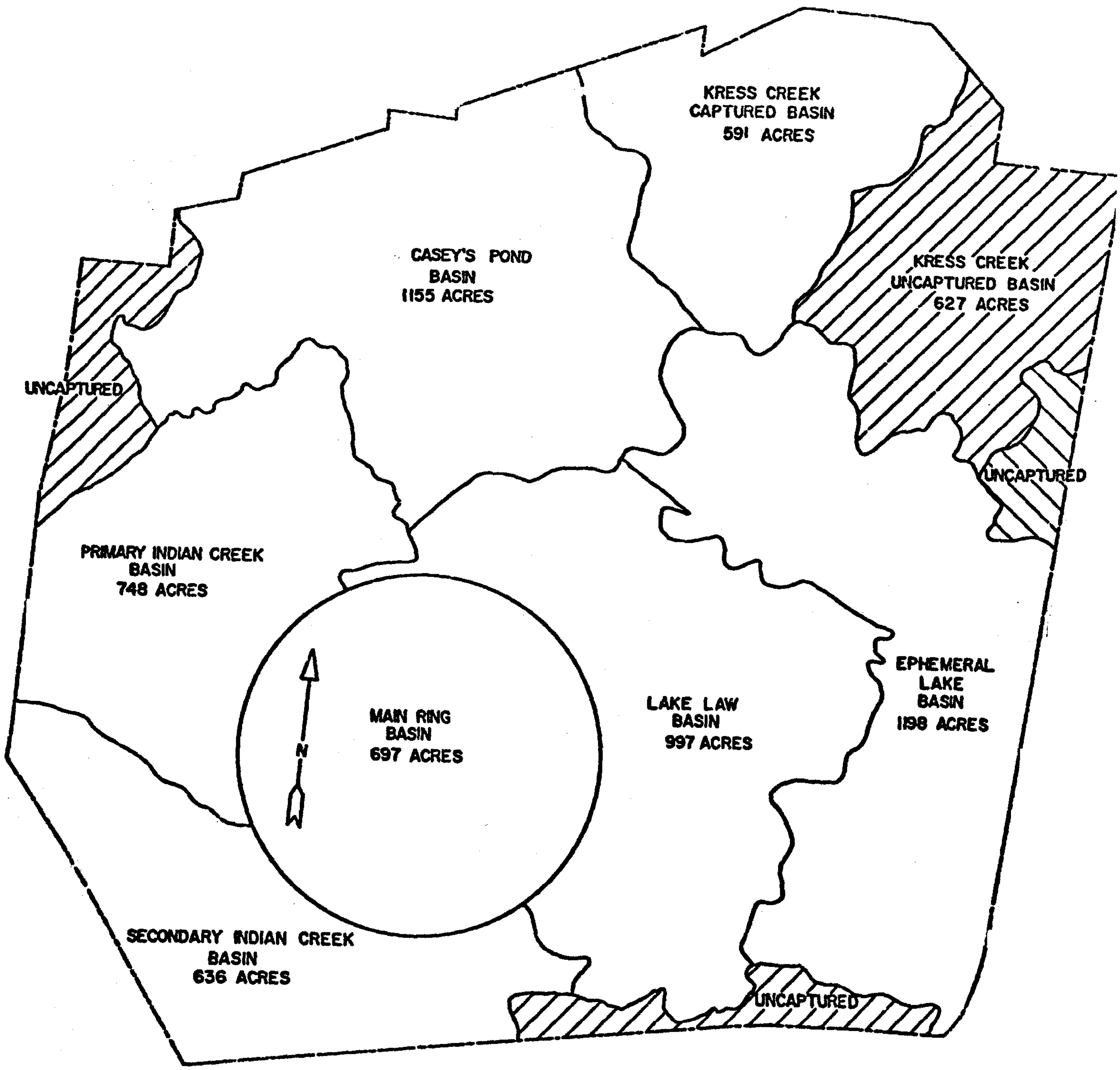


FIGURE I

RUNOFF BASINS

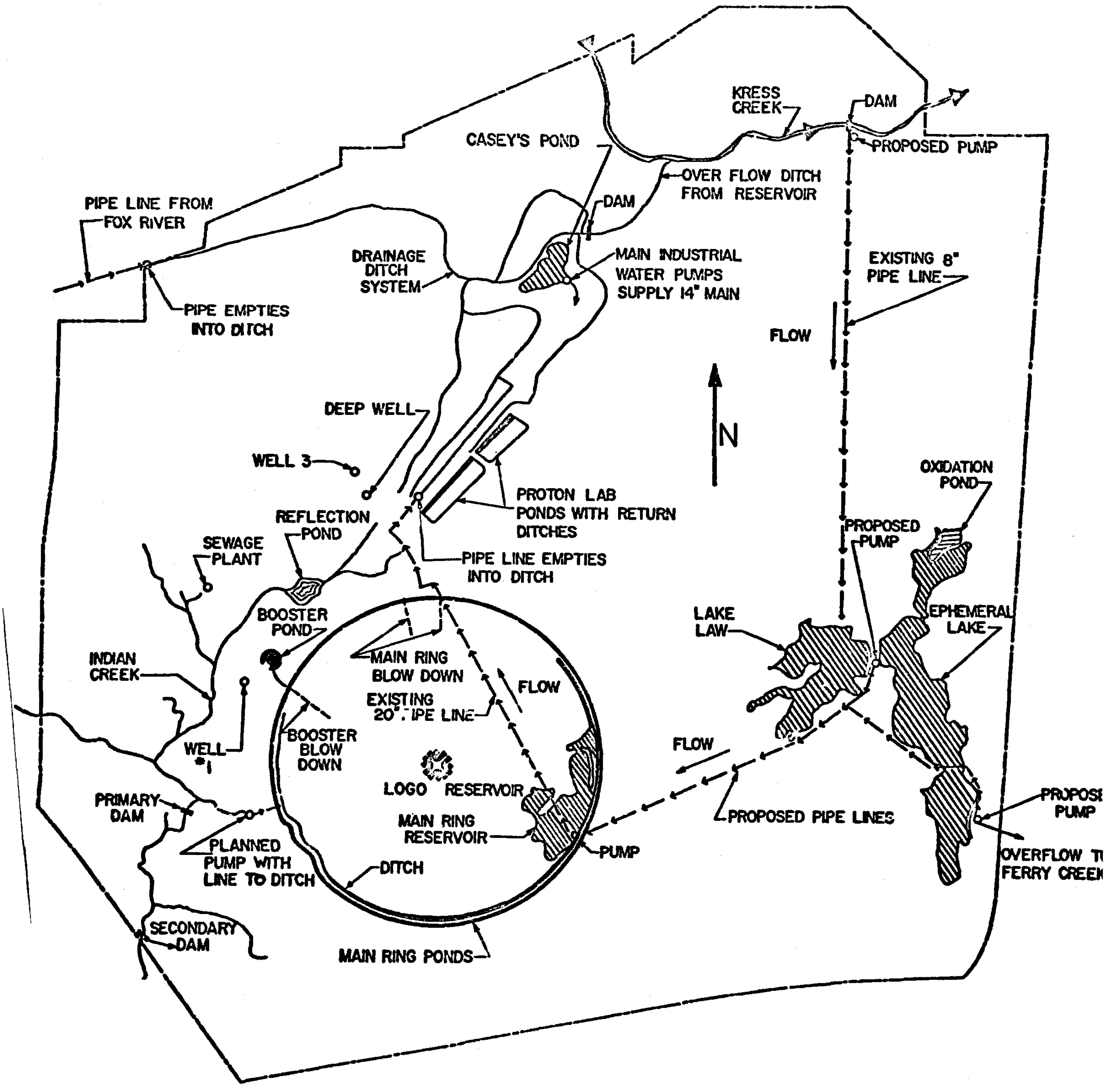
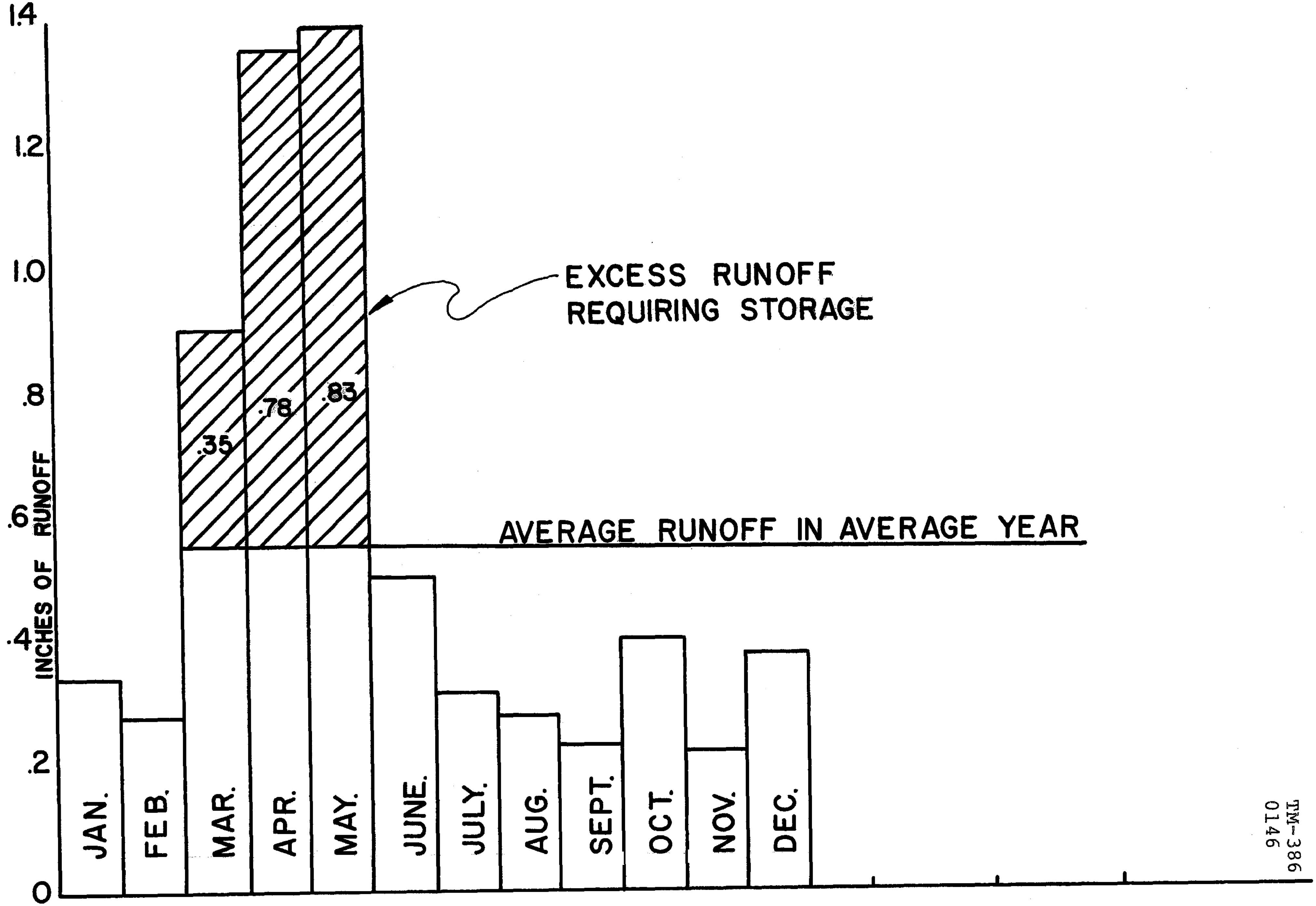


FIGURE 2

RESERVOIRS & DISTRIBUTION SYSTEMS



MONTHLY RAINFALL RUNOFF IN AVERAGE YEAR

FIGURE 3